RCC Dam Construction

Examples, project details, and design considerations

by Randall P. Bass and Gary Horninger

Roller-compacted concrete (RCC) is a low- or no-slump concrete mixture, typically placed with earth-moving equipment, for mass concrete applications. It differs from soil cement in that it is typically batched with engineered aggregates and has a higher cement content, resulting in greater compressive strength and durability.

RCC has been used to construct everything from dams to pavements. Its application for dams differs significantly from paving applications because dam placements must accommodate:

- Varying horizontal and vertical geometry;
- Limited access to the placement surface;
- Horizontal RCC lift placements of about 1 ft (0.3 m) compacted thickness;
- Integration of facing systems to protect RCC from exposure and provide a watertight barrier on the upstream face only; and
- The need to incorporate spillways, outlet works, galleries, joint treatments, and other features and treatments.

The type and configuration of a dam are primarily dictated by site conditions. Earth embankment gravity dams, for example, are well suited for sites with deep bedrock or soft foundation material. Straight RCC gravity dams are good candidates for sites with rigid foundation material and well-defined valleys with steep side slopes. It is also possible to incorporate bends into RCC gravity dams to take advantage of favorable foundation or abutment conditions. In contrast to earth embankment dams, RCC dams can be constructed with integral, wide spillways. This provides a significant cost advantage for projects that require large flood routing capacity, as large spillways for earth dams must be constructed separately from the dam.

RCC in Dam Construction

Some sites are suitable for composite dams comprising two or more construction types. Deep Creek Dam in Yadkin County, NC, is one such example. The dam site has shallow, competent bedrock on the right side of the valley and deeper, more variably weathered rock on the left side of the valley. The cost-efficient solution was to construct a 23 m (75 ft) high RCC gravity spillway and abutment closure section over the competent bedrock, coupled with a zoned earth embankment for the remainder of the impounding structure (Fig. 1). For such structures, special attention must be given to the interfaces between the deformable earthfill and rigid RCC materials. Cohesive soils compacted at optimum moisture

Fig. 1: Deep Creek Dam is a composite dam with an RCC gravity spillway and abutment closure section and an earth embankment section: (a) completed dam *(© photo courtesy of Aerial Photo Pros)*; **and (b) construction of the earth embankment section** *(© photo courtesy of Sky Site Images)*

content must be used at the wraparound to limit seepage and allow settlement of the embankment along the contact. Also, the chimney drain in the embankment must extend the full length of the downstream wrap. Other composite dams have been constructed using RCC and rockfill embankments, including the Saluda Dam in South Carolina and Duck River Dam in Alabama.

RCC gravity dam construction can also be used to build self-contained embankments. Taum Sauk Dam, in Reynolds County, MO, is an outstanding example—with a total length of over 1 mile (1.6 km), it holds the U.S. record for the quantity of RCC placed for a dam. The structure contains a hydroelectric pumped storage reservoir atop Proffit Mountain (Fig. 2). The unusual kidney bean shape was necessary to maximize storage volume.

RCC can also be used to raise existing concrete dams. For example, the original concrete San Vicente Dam in San Diego CA, was raised 117 ft (35.7 m) by building up the section on the downstream side (Fig. 3). To date, this is the largest RCC construction dam raise in the world.

Fig. 2: Taum Sauk Dam, designed by Paul C. Rizzo Associates, Inc., is composed of several million yd^3 of RCC and with inner and outer facings of conventional concrete *(photo courtesy of ASI Construction LLC)*

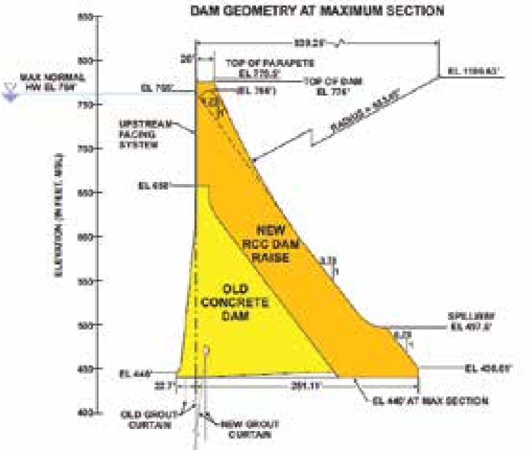


Fig. 3: RCC was used to raise the San Vicente Dam *(illustration courtesy of MWH, a Stantec company)*

Other examples of RCC dams in the United States include Big Haynes Creek near Conyers, GA; Hunting Run Dam near Fredericksburg, VA; and Portugués Dam near Ponce, Puerto Rico. The latter project was designed as an RCC arch-gravity dam that transfers some loading to the abutments through its arched shape (Fig. 4).

Project details and design concerns

For dam construction, RCC is placed in 1 ft lifts. The lifts make it easy to form steps that provide macro roughness elements in RCC spillways. The step and riser elements create turbulent pockets that provide significantly more energy dissipation than can be obtained using a smooth chute. The turbulence also bulks spillway flows with an increased amount of entrained air, resulting in lower residual energy at the basin and a much-reduced potential for cavitation (shock wave damage from water vapor bubble collapse). Thus, designers can use smaller terminal stilling basins.

Lift interfaces and joints require special attention to protect against seepage and damage. Leakage is mitigated using a facing that includes a robust positive water barrier. Because dams can be subjected to vegetation growth, weathering, and cyclic freezing, facing systems are also used on downstream faces. Typical facings comprise precast concrete, conventional concrete, or grout-enriched RCC (Fig. 5), any of which create a durable and resilient shell for the RCC mass.

Fig. 4: The RCC arch-gravity Portugués Dam has a total length of 1230 ft (375 m) *(photo courtesy of U.S. Army Corps of Engineers)*

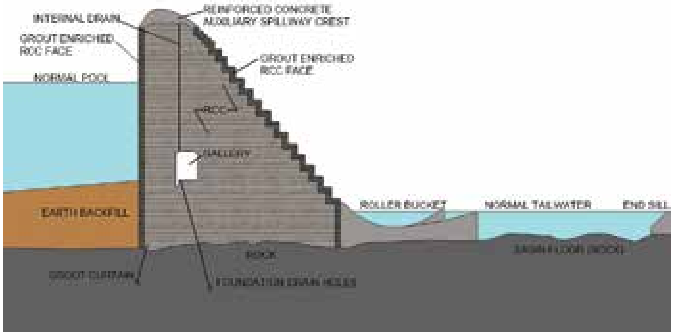


Fig. 5: Grout-enriched section at Deep Creek Dam *(© illustration courtesy of Schnabel Engineering)*

Fig. 6: A grout-enriched facing mixture is placed between previously placed RCC and formwork: (a) a mechanical vibrator is used to consolidate and combine the two mixtures; and (b) a completed test section *(© photos courtesy of Schnabel Engineering)*

Grout enrichment is the addition of a cementitious grout to the face of the RCC placement to effectively increase the cement content and density of the mixture (Fig. 6). RCC is held back from the formed face and the grout is introduced and mechanically vibrated to consolidate and combine with the RCC.

Because they are completed as part of the RCC lift placements, grout-enriched facing systems are less intrusive to the overall project schedule than conventional concrete facings. Current placement technologies do not result in a stable air void matrix within the grout, so grout-enriched facing systems are used only in climates that rarely experience freezing-and-thawing cycles. However, research is underway to optimize the stability of the air matrix within the grout and to refine the grout placement and consolidation methods.

RCC dam facing has also been constructed using geomembranes attached to precast concrete panels. Precast concrete facing panels are typically tied into the RCC lifts with anchors (Fig. 7), and installation can involve several processes if the panels include a liner requiring thermal welding and testing prior to RCC placement. Over the last two decades, exposed liner systems have been placed on the upstream face of older dams with seepage problems as well as on new dams. Because these systems are placed directly on the upstream face of the dam after it is completed, RCC production rates are not impacted.

Fig. 7: Facing panel installation with anchors embedded between RCC lifts *(© photo courtesy of Schnabel Engineering)*

Test section

Construction of a test section is a common project requirement with RCC dams (Fig. 8). This allows the contractor to demonstrate that the proposed means, methods, and equipment are capable of meeting project specifications. Lift joints, facing system, and consolidation of the RCC mixture can be also evaluated using a test section. If tests

Fig. 8: A test section is used to demonstrate conventional concrete facing for Taum Sauk Dam *(photo courtesy of ASI Construction LLC)*

Fig. 9: Two views of Hickory Log Creek Dam, Cherokee County, GA, with a stepped spillway that rises to 180 ft (55 m), making it the tallest RCC dam in the state and the fourth tallest in the world at the time of its construction *(© photos courtesy of Schnabel Engineering)*

Fig. 10: Fox Creek Dam, Fleming County, KY, is an example of an ogee weir cast over RCC *(© photo courtesy of Schnabel Engineering)*

indicate the need for modifications, the test section can be further segmented to verify acceptable results. Another benefit of test section construction is that the contractor's workforce becomes familiar with the materials and optimum placement processes prior to beginning work on the dam.

Spillways

A properly designed spillway will safely dissipate kinetic energy that accumulates as the flow accelerates down the chute. For RCC dams, conveyance and dissipation are accomplished through one or more of the following: stepped spillway chutes, straight or converging smooth chutes, flip buckets, and stilling basins. When highly concentrated flows, high heads, nonstandard design geometries, or unusual operations are encountered, it is beneficial to conduct scale model studies to verify conventional simulations of flow conditions. Such studies can uncover issues that are not readily apparent through conventional analyses and computer models.

Stepped spillways—the chutes downstream of spillway control sections—have been constructed using the stepped RCC placement technique (Fig. 9). Spillway step sizing is strongly influenced by hydraulic requirements, but step height is normally an even multiple of RCC lift thickness. This approach improves hydraulic performance while facilitating project construction sequencing and cost containment. As previously stated, the surfaces of stepped spillways are formed using conventional concrete or grout-enriched RCC. Stepped spillways are generally constructed with training walls to guide discharges down the face of the dam. For some projects, the spillway is incised within the cross section of the nonoverflow portion of the dam, with the turned section of the RCC mass faced with conventional concrete to perform the function of training walls.

Ogee weirs (Fig. 10), sharp crested weirs, and a variety of gates have been constructed on the crest of RCC dams as control sections. These structures involve the integration of cast-in-place sections with the top lifts of RCC at the spillway location. The conventional concrete is anchored into the RCC mass for stability.

Other Design Considerations

This article can't cover all RCC dam design and construction considerations in detail. However, it is possible to highlight some of the key issues that dam designers must consider.

Intakes/outlets and internal galleries

Unlike paving applications, RCC dams generally have obstructions such as intake/outlet structures and internal galleries (Fig. 5). These features interrupt the continuous placement of RCC material. Intake/outlet structures may be conventional cast-in-place concrete towers constructed upstream of the main dam. The outlet conduit typically passes through the placement footprint, and this requires special attention to detail. It is likely that RCC will be placed below and around the conduit, but special treatment is recommended around the conduit perimeter to prevent seepage at the interface between the conventional concrete and RCC.

Internal galleries are also common for RCC dams. Galleries permit access to the interior of the dam for inspection. They also collect water from internal, foundation, and face drains. Galleries can be constructed by mining the RCC. Alternatively, they can be formed of conventional or precast concrete.

Mined RCC galleries involve staged placement of loose, uncemented material that is subsequently excavated when the RCC placement reaches a set elevation. The resulting rough-faced walls of the gallery allow direct inspection of the RCC inside the dam.

Formed galleries are constructed by placement of braced forms (conventional formwork or precast concrete) at the gallery location and placing RCC or conventional concrete adjacent to the forms. Formed galleries will generally have smoother walls than mined galleries, but they hinder direct inspection of the RCC inside the dam. A variation of this concept is to construct a grout-enriched formed gallery, using similar procedures as used for grout-enriched facing.

Cracking and joints

RCC dams can bear significant hydraulic loads and are thus subject to seepage. Uncontrolled cracking in the RCC monolith is undesirable for both seepage and load-bearing considerations, so efforts must be taken to control cracking caused by factors such as:

- Local and global stresses and strains induced by thermal loads (that is, inadequate management and control of heat of hydration);
- Foundation discontinuities such as sharp vertical elevation changes;
- Variations in load deformation of adjacent foundation materials; and
- Stress concentrations near sharp transitions in dam geometry.

Some cracking issues are common to most dam sites, while others reflect responses to site-specific issues. While cracking can be minimized by mitigating the causative factors, some situations dictate the creation of a purposeful crack—a transverse joint depending on the length of the dam and the size of the placement. If cracking cannot be tolerated, provisions must be incorporated into the design to maintain structural integrity and adequate seepage control.

Transverse joints are constructed in several ways. One common method is to use a steel plate to insert polyethylene film into the RCC lift. The plastic sheet is wrapped around the

Fig. 11: Transverse joint construction by inserting and removing a plate in fresh RCC *(© photo courtesy of Schnabel Engineering)*

plate and a loader or other machine is used to press the wrapped plate through the lift thickness. Such joints are located where seepage can be collected and monitored. Figure 11 illustrates joint construction in the RCC placement by inserting and removing a steel plate in the RCC.

Horizontal joints also receive special attention. To maximize the bond between each RCC lift, specifications require lift surfaces to be kept clean and moist. Specifications also generally establish a maximum RCC lift surface exposure, in degree hours, beyond which the contractor is required to apply a bedding mortar on the noncompliant lift surface immediately prior to placement of the next lift.

Placement

RCC dams may also require additional attention to the cleanliness of the lift joints, placement of bedding mortar at conduit encasement perimeters, and the temperature of the fresh mixture and the placement. It is not uncommon to pressure wash and vacuum the surfaces between lifts, and bedding mortar may also be required.

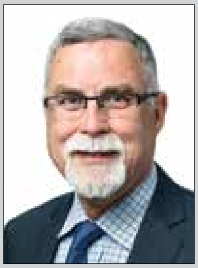
Bedding mortar is typically a sand-cement mortar mixture that is spread thinly across the lift joint immediately before the next RCC lift is placed to promote bonding between the lifts. A retarding admixture may be specified for the bedding mortar to maintain workability and allow the subsequent RCC lift to be placed. Bedding mortar is typically deposited from the mixer truck or conveyor and spread with squeegees by hand.

Temperature control takes on greater importance in dams than in some other RCC applications. Specifications usually have temperature restrictions for both the fresh RCC mixture and the placement temperature. Some specifications may limit the maximum temperature of the fresh RCC to 75°F (24°C). This may require precooling the aggregates, placement at night, or other measures including ice or liquid nitrogen cooling.

Summary

RCC dams are ideal for sites with relatively shallow, rigid foundation material, particularly if the sites require large flood routing capacities. Although RCC dams require facing materials for protection against seepage and environmental damage, RCC lift construction facilitates the creation of stepped spillways that efficiently dissipate energy. Other design considerations include galleries, transverse joints, and bond between RCC lifts.

Selected for reader interest by the editors.



Randall P. Bass, Principal at Schnabel Engineering, joined the company in 2004. His dam engineering career began with the Georgia Safe Dams Program, followed by a work history that includes a national civil engineering firm and the Portland Cement Association, where he focused on RCC and soil cement for water resources applications. Bass has participated in several dam owner training workshops and was on a peer review team for the U.S. Army Corps of Engineers' national dam safety program. He received his BS and MS in civil engineering from the Georgia Institute of Technology, Atlanta, GA. Bass is active in the Association of State Dam Safety Officials and the United States Society on Dams. He is a licensed professional engineer in Georgia and several other states.

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